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Plinthite and Its Associated Evolutionary Forms in Soils and Landscapes: A Review

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ABSTRACT

At elevated temperature regimes and abundant precipitation, mobilization and accretion of weathered iron oxides are promoted especially in a reduced environments in the tropics. This may lead to the formation of plinthite, which hardens irreversibly upon repeated wetting and drying to form petroplinthite. The need for this review stems from the seemingly dearth of information on the subject and a need to clarify different terms used in describing plinthite. We review various research works on plinthite and its associated pedogenic forms in the tropics. Furthermore, we proffer recommendations as to the most appropriate land use management practices that could help minimise the environmental and agronomic problems associated with plinthite and its related pedogenic forms. Parent material, temperature, seasonality and geomorphology are critical factors that influence soil water regime which in turn affect the pedogenesis of plinthite. Soil pH and mineralogy are additional factors that could also promote plinthite formation. Fossil plinthic soils are potential proxies for palaeoenvironmental reconstruction. Measures used in the management of plinthic soils include mechanically breaking the hardpans and the use of organic and inorganic amendments to modify the structure and chemistry of the soils. Avoidance of practices that would predispose soils to erosion would also prevent plinthization. We call for the relinquishment of the term "laterite" which is a general term for all forms of iron oxide-enriched earthy materials as used for plinthite. Plinthic horizon should also be incorporated into the United States Department of Agriculture Soil Taxonomy in view of its growing importance in soils.

Key Words: agronomy, pedogenesis, petroplinthite, soil taxonomy, tropics

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From a pedogenetic perspective, tropical environments are those with mean monthly temperatures of at least 18 °C and where soils are isothermic (Van Wambeke, 1992). These environments are characterised by four major ecological zones: savannas and associated grasslands cover approximately 49% of the land area; evergreen forests 24%; and desert and semi desert 16% and 11%, respectively (Van Wambeke, 1992). Approximately 23% of the tropics lie at elevations that exceed 900 m above sea level; such areas constitute the tropical highlands (Sanchez and Buol, 1975).

Most soils on tropical highlands and, to a lesser extent, soils at lower elevations in the tropics have prominent iron (Fe) and/or manganese (Mn)-rich formations that are present as hardpans (crusts), flakes, nodules, and wet/moist unconsolidated forms at variable depths (Sanchez and Buol, 1975; Coelho Vidal-Torrado, 2003a; Le *et al.*, 2008). The origin of these pedogenic features, more often than not, is attributed to fluctuations in the groundwater table (Eswaran *et al.*, 1990; Van Wanbeke, 1992; Breuning-Madsen *et al.*, 2007; Asiamah, 2008) and the subsequent repeated oxidation and reduction conditions, eventually leading to the solubilization and translocation of the Fe and Mn oxides in the soils (Soil Survey Staff, 2010). The resulting layer becomes enriched with Fe and Mn oxides due to the selective removal of silica (desilication) and the accumulation of sesquioxides (oxides of Al and Fe). Desilication takes place during strong chemical weathering as observed in most tropical soils and landscapes (Dos Anjos *et al.*, 1995; Davies, 1997; Asiamah, 2008).

These soft and Fe-rich materials in soils were first referred to as "laterite" by the British geologist F. Buchanan-Hamilton in 1807 (Showers, 2005). Since then, the term "laterite" has been widely applied and, arguably, misapplied. The use of the term "plinthite" is now universally preferred by pedologists and soil geographers (see below). Plinthite (derived from the Greek

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word *"plinthos"* which means stone) is defined as an Fe-rich, humus-poor mixture of clay with quartz and other diluents that, on exposure to repeated wetting and drying, changes irreversibly to an iron-stone hard-pan or an irregular soil aggregate (Soil Survey Staff, 2010). It commonly occurs as dark red redox concentrations that usually form platy, polygonal, or reticulate patterns. Plinthite is generally characterised by a high content of Fe (in the form of hematite, goethite, and poorly crystallised oxide compounds) and/or aluminium in relation to other components (Lal and Stewart, 2005; Soil Survey Staff, 2010). However, it can be distinguished from Fe-enriched earth materials that are not plinthite as other concretions do not irreversibly harden upon repeated exposure to oxygen-rich environments. The irreversibly hardened plinthite is generally referred to as "petroplinthite" which is also known as "ironstone" (Eswaran *et al.*, 1990; Beinroth *et al.*, 1996; Soil Survey Staff, 2006).

The pedogenesis, occurrence, and distribution of plinthite and its associated pedogenic evolutionary forms such as petroplinthite, pisolithic nodules and ferricretes in tropical soils are a subject of interest because of their inherent agronomic, palaeoenvironmental, industrial and economic importance. Plinthite and its related forms could give snapshots of the past environment under which they formed, since their nature preserves them from being completely eroded during environmental changes. This has proved to be an invaluable tool for scientists involved in palaeoenvironmental and palaeoclimatic reconstructions (Ding *et al.*, 1998; Guo *et al.*, 2002; Liu *et al.*, 2003; Hao and Guo, 2007).

Secondly, the growing human population in most tropical countries creates the need for increased agricultural production. As to lend weight to the problem, industrial and residential expansions compete with agriculture for fertile lands. Consequently, land degradation caused by the abundant presence of plinthite and anthropogenic human activities has limited the maximal use of arable lands. This has continued to pose a severe threat to food security in many parts of the tropical world as it poses a serious constraint to land use (Asiamah and Dedzoe, 2004; Asiamah, 2008).

Various studies (*e.g.*, Lucas *et al.*, 1986; Tardy *et al.*, 1997; Jien and Chen, 2006) document the hardened form, petroplinthite, but the soft form, plinthite, has received less attention (Asiamah and Dedzoe, 2004) despite the fact that this form also results in land use limitations. It is therefore timely to review both the positive and negative effects of these pedogenic formations in soils and landscapes. An extensive literature search shows that there is limited and widely scattered information on plinthite in tropical soils and landscapes.

Thus, the objectives of this paper were to review the available findings of research scientists on the origin and development, distribution, properties and taxonomy of plinthite and its associated forms in tropical soils and landscapes and to explore applications of this knowledge in agronomic, industrial and palaeoenvironmental contexts. Furthermore, we aimed to review and reassess sustainable management practices for such formations in their provenance localities. This, we believe, would go a long way in bridging a lingering conceptual and literature gap amongst soil scientists, geographers, pedologists, geologists and other stake holders.

GLOSSARY OF TERMINOLOGIES

We explain, based on Soil Survey Staff (2010) and IUSS Working Group WRB (2006), the most often used terms as:

Laterite: In *sensu stricto*, this is a general term used for all Fe-enriched terrestrial pedochemical and geochemical sediments very poor or lacking in organic matter and found near the earths' surface. It does not take shape, texture or structure of the material into consideration. The term, unarguably, has been abused. One of the key objectives of this paper, therefore, was a call to the soil science, geography and ecology community to abandon its use as it means different things to different professionals and would hamper effective scientific communication.

Plinthite: This refers to the soft form of Fe-rich, organic poor earthy materials, rich in sesquioxides and having not undergone irreversible hardening. However, it does not slake in water (Daniels *et al.*, 1978). Plinthite is separable from the soil matrix and can withstand rolling between fingers. A complete and up-to-date definition by Soil Survey Staff (2010) has been stated in the introductory section.

Petroplinthite: This forms as a result of strong chemical weathering and segregation of plinthite. Petroplinthite, also known as ironstone, is associated with ferric soil properties. Upon repeated wetting and drying, plinthite, which is soft in consistency, would harden irreversibly to form petroplinthite. It forms a continuum, interconnected fractured or broken sheets of nodules or mottles if they are 15 percent or more by volume in soils and landscapes. A soil horizon where these internodular matrices largely depleted of Fe oxide occur is referred to as "ferric horizon" (IUSS Working Group WRB, 2006).

Pisolith: This is a petroplinthitic nodule with a